L Number	Hits	Search Text	DB	Time stamp
3	3903	lowest adj2 rate	USPAT; US-PGPUB; EPO; JPO; DERWENT	2004/10/21 12:44
4	0	(retrain$5 near5 equaliz$5) same (lowest adj2 rate)	USPAT; US-PGPUB; EPO; JPO; DERWENT	2004/10/21 12:44
5	184	retrain$5 same equaliz$5	USPAT; US-PGPUB; EPO; JPO; DERWENT	2004/10/21 12:44
6	0	(retrain$5 near5 equaliz$5) same (lowest adj2 rate)	USPAT; US-PGPUB; EPO; JPO; DERWENT	2004/10/21 12:44
7	1	(retrain$5 near5 equaliz$5) and (lowest adj2 rate)	USPAT; US-PGPUB; EPO; JPO; DERWENT	2004/10/21 12:44
2	95	retrain$5 near5 equaliz$5	USPAT; US-PGPUB; EPO; JPO; DERWENT	2004/10/21 12:47
8	1516	train$5 near5 equalizer	USPAT; US-PGPUB; EPO; JPO; DERWENT	2004/10/21 12:48
9	36	(retrain$5 near5 equaliz$5) and (train$5 near5 equalizer)	USPAT; US-PGPUB; EPO; JPO; DERWENT	2004/10/21 14:34
10	944326	incorrect$3 or error	USPAT; US-PGPUB; EPO; JPO; DERWENT	2004/10/21 14:34
11	548	re adj1 train$5	USPAT; US-PGPUB; EPO; JPO; DERWENT	2004/10/21 14:35
12	15	(re adj1 train$5) near6 equaliz$5	USPAT; US-PGPUB; EPO; JPO; DERWENT	2004/10/21 14:36
13	5	(incorrect$3 or error) same ((re adj1 train$5) near6 equaliz$5)	USPAT; US-PGPUB; EPO; JPO; DERWENT	2004/10/21 14:36

US-PAT-NO: 6307901

DOCUMENT-IDENTIFIER: US 6307901 B1

TITLE: Turbo decoder with decision feedback equalization

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Abstract Text - ABTX (1):
A decoder equalizes a turbo coded signal with intersymbol interference by performing a decision-feedback equalization in each iteration of the turbo decoding process. In such iteration process, two recursion processors calculate soft output values for the information bits and the coded bits of the signal as well. Hard output values are derived from the soft output values. A decision feedback equalizer in an iterative loop of the decoder receives the hard output values uses these to provide a correction for the intersymbol interference. Thereafter, the decision feedback signal applies the correction signal to the input signal to minimize the intersymbol interference.

Brief Summary Text - BSTX (4):
Convolutional codes are often used in digital communication systems to protect transmitted information from error. Such communication systems include the Direct Sequence Code Division Multiple Access (DS-CDMA) standard IS-95, the Global System for Mobile Communications (GSM), and next generation wideband communication systems. Typically in these systems, a signal is convolutionally coded into an outgoing code vector that is transmitted. At a receiver, a practical soft-output decoder, such as a Viterbi decoder as is known in the art, uses a trellis structure to perform an optimum search for the transmitted signal bits based on maximum likelihood criterion.

Brief Summary Text - BSTX (5):
More recently, turbo codes have been developed that outperform conventional coding techniques. Turbo codes are generally composed of two or more convolutional codes and turbo interleavers. Turbo decoding is iterative and uses a soft output decoder to decode the individual convolutional codes. The soft outputs of one decoder feed into the next decoder or feedback to the first decoder when the decoding procedure iteratively approaches the converged final results. The soft output decoder is usually a MAP (maximum a posteriori) decoder which requires backward and forward recursions to determine the soft output. MAP derivatives are also available including log-MAP, max-log-MAP, soft-output Viterbi algorithm (SOVA), and constant-log-MAP algorithms, as are

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TURBO DECODER WITH DECISION FEEDBACK EQUALIZATION

FIELD OF THE INVENTION

This invention relates generally to communication systems, and more particularly to a decoder for use in a receiver of a turbo coded communication system.

BACKGROUND OF THE INVENTION

Convolutional codes are often used in digital communication systems to protect transmitted information from error. Such communication systems include the Direct Sequence Code Division Multiple Access (DS-CDMA) standard IS-95, the Global System for Mobile Communications (GSM), and next generation wideband communication systems. Typically in these systems, a signal is convolutionally coded into an outgoing code vector that is transmitted. At a receiver, a practical soft-output decoder, such as a Viterbi decoder as is known in the art, uses a trellis structure to perform an optimum search for the transmitted signal bits based on maximum likelihood criterion.

More recently, turbo codes have been developed that outperform conventional coding techniques. Turbo codes are generally composed of two or more convolutional codes and turbo interleavers. Turbo decoding is iterative and uses a soft output decoder to decode the individual convolutional codes. The soft outputs of one decoder feed into the next decoder or feedback to the first decoder when the decoding procedure iteratively approaches the converged final results. The soft output decoder is usually a MAP (maximum a posteriori) decoder which requires backward and forward recursions to determine the soft output. MAP derivatives are also available including log-MAP, max-log-MAP, soft-output Viterbi algorithm (SOVA), and constant-log-MAP algorithms, as are known in the art.

Turbo coding is efficiently utilized to correct errors in the case of communicating over an added white Gaussian noise (AWGN) channel. However, in the presence of intersymbol interference (ISI), the performance of turbo decoding is degraded. Some prior art methods have included equalization to mitigate ISI. However, these techniques are either too complicated to be implemented in practice or they introduce extra delay in receiver.

There is a need for a decoder that reduces errors due to distortion in ISI channels, and in particular, there is a need for an improved decoder that can equalize an ISI channel to reduce errors without introducing any additional delay. It would also be of benefit to provide a decoder with a minimal increase of circuitry or computational complexity.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 shows a trellis diagram for convolutional encoding schemes as are known in the prior art;

FIG. 2 shows a simplified block diagrams representing noise and distortion introduction in a coded signal, as is known in the prior art;

FIG. 3 shows a simplified block diagram for a turbo encoder as is known in the prior art;

FIG. 4 shows a simplified block diagram for a turbo decoder as is known in the prior art;

FIG. 5 shows a simplified block diagram for a turbo decoder with equalization, in accordance with the present invention;

FIG. 6 shows simplified block diagram for the decision

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FIG. 7 shows a method for turbo coding with equalization, in accordance with the present invention; and

FIG. 8 shows a graphical representation of the improvement provided by the present invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

The present invention provides a turbo decoder coupled with a decision feedback equalizer (DFE) so that the performance of the turbo decoding is improved for a turbo encoded signal transmitted over an ISI channel. Moreover, the present invention accomplishes this improvement without a great increase in complexity by including the DFE in the iterative loop.

Typically, convolutional codes, turbo codes, and others are graphically represented as a trellis as one shown in FIG. 1 where a four state, five section trellis is shown. For convenience, we will reference M states per trellis section and N trellis sections per block or frame. Maximum a posteriori type decoders (log-MAP, MAP, max-log-MAP, constant-log-MAP, etc.) utilize forward and backward generalized Viterbi recursions or soft output Viterbi algorithms (SOVA) on the trellis in order to provide soft outputs, as is known in the art. The MAP decoder minimizes the decoded bit error probability for each information bit based on all of the received signal in one encoding block or encoding frame.

Because of the Markov nature of the encoded sequence (wherein, given the current states, previous states cannot affect future states or future output branches), the a posteriori bit probability can be broken into the past (beginning of trellis to the present section), the present (branch metric for the current section), and the future (end of trellis to current section). More specifically, the MAP decoder performs forward and backward recursions up to a present section wherein the past and future probabilities are used along with the present branch metric to generate an output decision. The principles of providing hard and soft output decisions on information bits are known in the art, and several variations of the described decoding methods exist. Most of the soft input-soft output (SISO) decoders considered for turbo codes are based on prior art MAP algorithms such as that presented in a paper by C. Berrou, A. Glavieux, and P. Thitimajshima, entitled "Near Shannon Limit Error-Correcting Coding and Decoding: Turbo-Codes (1)", Proceedings ICC, 1993, pp. 1064–1070. (Berrou algorithm).

For simplicity and without loss of generality, we consider a digital equivalent baseband communication system depicted in FIG. 2, where the information sequence b_i is turbo encoded, mapped to channel symbols a_i which is either 1 or -1, passed through a channel interleaver π_c and transmitted over a minimum phase ISI channel. At receiver end, the received signal y_i is distorted and can be expressed as

$$y_i = \sum_{j=0}^{L} b_j a_{i-j} + n_i$$

where b_j represents channel impulse response, L denotes ISI length and n_i is AWGN. Distortion due to ISI and AWGN increases the likelihood of bit errors when a receiver attempts to decode the signal to obtain the original information bits b_i. The use of turbo decoding alone in the receiver will successfully minimize bit error due to the AWGN, but something more is needed to minimize bit error due to ISI.

FIG. 3 shows a typical turbo encoder that is constructed